Specification

Title of the Invention

5 [0001]   Objective Lens For Optical Pick-Up

Background of the Invention

[0002]   The present invention relates to an objective

10 lens for an optical pick-up of an optical disc drive, which

is capable of reading/writing data from/to a plurality of

kinds of optical discs whose cover layers have different

thicknesses. In particular, the present invention relates

to an objective lens formed with a diffractive lens

15 structure on a surface of a refractive lens.

[0003]   Generally, an optical pick-up for an optical disc

drive is provided with a laser source, such as a laser

diode, an objective lens which converges the laser beam

emitted by the laser source on an information layer of the

20 optical disc to form a beam spot thereon, and a signal

detecting system that receives the laser beam which is

reflected by the information layer of the optical disc and

passes through the objective lens. The signal detecting

system produces various signals based on the received laser

25 beam.

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[0004]   There are various types of optical discs on which digital information is recorded at various densities, respectively. An effective diameter of an objective lens of an optical pick-up depends on an NA (numerical aperture), which is determined based on the density of the information recorded on the optical disc.

[0005]   Generally, an objective lens used for a compact optical pick-up is made of a resin and is formed by means of an injection molding. A flow of material of a lens in the process of the injection molding is easily disturbed at an outer portion thereof and/or at a portion where the shape of the lens changes by a large amount. Therefore, in order to fabricate a lens having a necessary performance even at the outermost area within the effective diameter thereof, it is preferable that the lens has an outer diameter which is sufficiently larger than the effective diameter thereof, so that the change of the shape of the lens at the peripheral portion within the effective diameter area is prevented.

[0006]   However, if the objective lens is optimized so that the above condition is satisfied, the optical performance of the lens at portions in the vicinity of the effective diameter may be continuous since the change of the shape is relatively small at the portions. This means that the effective diameter is substantially enlarged,

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which causes a bad influence on the formation of the beam spot on the optical disc. That is, if the effective diameter becomes greater, the NA becomes greater, which results in reduction of the size of the beam spot. Further, in such a configuration, if the optical disc inclines with respect to the objective lens, too much aberration occurs, which prevents recording/reading of the digital information on the optical disc.

[0007]   However, if the peripheral portion outside the effective area of the objective lens is not optimized, due to the aberration caused by the peripheral portion, the size of the beam spot may become larger, which also prevents recording/reading of the digital information on the optical disc.

[0008]   In order to avoid the above problems, in the prior art, an aperture stop member is provided on the light source side of the objective lens so that the beam incident on the objective lens is confined to the effective area thereof.

[0009]   However, if the aperture stop member is located on the light source side of the objective lens, a size of an optical system of the optical pick-up along an optical axis direction increases, which prevents the downsizing of the optical system of the optical pick-up.

Summary of the Invention

[0010]   It is therefore an object of the present invention to provide an objective lens for an optical pick-up, with which light passing through the peripheral area, which is outside the effective area, does not have bad effect in forming a beam spot on an information layer of an optical disc without employing the aperture stop member.

[0011]   For the object, according to the invention, there is provided an objective lens for an optical pick-up, which is configured such that at least one surface of the objective lens is an aspherical surface. The at least one surface is divided into an effective area and an outer area which is an area outside the effective area. The effective area and the outer area are formed such that a predetermined gap is caused between a spherical aberration of a light beam passed through the effective area and a spherical aberration of a light beam passed through the outer area. The light beam passed through the effective area forms a beam spot on a predetermined surface, while the light beam passed through the outer area is diffused on the predetermined surface.

[0012]   With this configuration, due to the gap of the spherical aberrations of the beams respectively passed through the effective area and the outer area, the light

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passed through the outer area does not have bad effect in forming a beam spot on an information layer of an optical disc. Thus, if such a lens is used, it is unnecessary to employ the aperture member, and the optical performance

5   thereof will not be deteriorated.

[0013]   Optionally, a diffraction lens structure may be formed on the at least one surface within the effective area. The outer area may be connected with a base curve which is a macroscopic shape of the at least one surface

10   within the effective area of the at least one surface.

[0014]   Further optionally, the diffraction lens structure may include a plurality of concentric annular zones formed on said at least one surface. A step in a direction of the optical axis may be formed at every border

15   between adjacent annular zones.

[0015]   It is preferable that an absolute value of the gap of the spherical aberrations may be substantially equal to or greater than 10 micrometers.

[0016]   In a particular case, the absolute value of the

20   gap may be approximately 200 micrometers.

[0017]   Still optionally, the surface of said outer area may be a continuous surface having no diffraction lens structure.

[0018]   According to another aspect of the invention,

25   there is provided an objective lens for an optical pick-up,

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at least one surface of said objective lens being an aspherical surface. The at least one surface may be divided into an effective area and an outer area outside said effective area. The effective area and the outer area may

5   be formed such that the light beam passed through the effective area forming a beam spot on a predetermined surface, while the light beam passed through the outer area is diffused on the predetermined surface.

10   Brief Description of the Accompanying Drawings

[0019]   Figs. 1A-1C schematically show configurations of an objective lens according to the present invention;

[0020]   Fig. 2 shows an optical system of an optical

15   pick-up that employs the objective lens shown in Fig. 1;

[0021]   Fig. 3 schematically shows an objective lens according to a first embodiment of the present invention;

[0022]   Figs. 4A-4C show aberrations of an optical system including the objective lens and a cover layer of the

20   optical disc shown in Fig. 3;

[0023]   Fig. 5 shows a spot diagram on the information layer of the optical disc when the objective lens according to the first embodiment is used;

[0024]   Fig. 6A-6C show aberrations of the optical system

25   including an objective lens according to a second

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embodiment; and

[0025]   Fig. 7 shows a spot diagram on the information
layer of the optical disc when the objective lens of the
second embodiment is used.

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Detailed Description of the Embodiments

[0026]   Fig. 1A, 1B and 1C schematically show a
configuration of an objective lens 10 according to an
10   embodiment of the present invention. Fig. 1A is a front
view, Fig. 1B is a cross-sectional view, and Fig. 1C is an
enlarged view of a part of Fig. 1B.

[0027]   The objective lens 10 is applicable to an optical
pick-up of an optical disc drive that is capable of
15   recording/reproducing digital information on/from a
plurality of kinds of optical discs (e.g., CD, CD-R and
DVD). The objective lens 10 functions to converge a laser
beam emitted by a laser diode onto an information layer of
an optical disc.

20   [0028]   The objective lens 10 is a biconvex plastic lens
having first and second surfaces 11 and 12 each of which is
a rotationally-symmetrical, aspherical surface. A
diffractive lens structure is formed on the first surface
11. As shown in Fig. 1A, the diffractive lens structure
25   includes a plurality of concentric annular zones. The

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diffractive lens structure has minute steps in an optical
axis direction at the boundaries between the annular zones,
likewise a Fresnel lens structure, as shown in Fig. 1C. The
second surface 12 is formed as a continuous surface without
5   such a diffraction lens structure.

[0029]   The first surface 11 is divided into an inside
area (which will also be referred to as an effective area)
Rin which is inside a circle of an effective diameter of
the objective lens 10, and an outside area Rout which is
10   outside the circle of the effective diameter of the
objective lens 10 (i.e., outside the effective area).

[0030]   According to the embodiment, the objective lens
10 is configured to be applicable to an optical pick-up
compatible to various types of optical discs, e.g., CD, CD-
15   R and DVD. For this purpose, the inside area Rin is divided
into a common area RC and a high NA exclusive area RE. The
common area RC contributes to converge a light beam at a
low NA, which is necessary and sufficient for an optical
disc having a low recording density such as a CD or a CD-R,
20   on the information layer of the optical disc. Both the
common area RC and the high NA exclusive area RE contribute
to converge a light beam at a high NA, which is necessary
for an optical disc having a high recording density such as
a DVD only, on the information layer of the optical disc.

25   [0031]   The diffractive lens structure is formed over the

entire effective area, which includes the common area RC
and the high NA exclusive area RE. The common area RC is
inside a circle at which a light beam whose NA is 0.45
through 0.50 passes, and the high NA exclusive area RE,

5 which surrounds the common area RC, is inside a circle at
which a light beam whose NA is about 0.60 passes.

[0032]   The outside area Rout is configured to be
continuous, without steps, and continuously connected from
a macroscopic base curve, which is indicated by dashed

10 lines in Fig. 1C, of the outer portion of the effective
area Rin. With this configuration, a certain amount of gap
in a spherical aberration is generated between the inside
area Rin and the outside area Rout. Specifically, the
absolute value of the gap of the spherical aberrations is

15 set to 10 micrometers or more so that the light beam
passing through the outside area Rout diffuses, while a
beam spot is formed by the light beam passed through the
inside area Rin.

[0033]   Optionally, another Fresnel lens structure may be

20 formed on the outside area Rout to generate a sufficient
gap in the spherical aberration between the inside area Rin
and the outside area Rout.

[0034]   Fig. 2 shows an exemplary optical system of the
optical pick-up that employs the objective lens 10

25 according to the invention. The optical system of the

optical pick-up includes a DVD module 21, a CD module 22, a

beam combiner 23, a collimating lens 24 and the objective

lens 10. Each of the modules 21 and 22 is provided with a

laser diode and a photo detector which are mounted on a

5   common substrate. The objective lens 10 is arranged to be

movable in the optical axis direction for focusing, and in

the radial direction of the optical disc for tracking, by

means of well-known focusing and tracking mechanisms,

respectively.

10   [0035]   The DVD is a thin cover type optical disc that

has higher recording density and the thickness of the cover

layer thereof is 0.6 mm. In order to form a small beam spot

on the DVD, a laser beam whose wavelength is within a range

of 635 nm through 665 nm is required.

15   [0036]   The CD-R and the CD are thick cover type optical

discs have a lower recording density. The thickness of the

cover layer of the CD-R or the CD is 1.2 mm. The CD-R

requires near-infrared radiation due to its spectral

reflectance.

20   [0037]   Therefore, the laser diode of the DVD module 21

emits a laser beam L_1 having a wavelength of 657 nm or 660

nm, and the laser diode of the CD module 22 emits a laser

beam L_2 having a wavelength of 785 nm or 790 nm.

[0038]   When the thin cover type optical disc D1 (shown

25   by the solid line) is used, the DVD module 21 is driven to

emit the laser beam L_1 which is shown by a solid line, and
a relative position of the objective lens 10 with respect
to the optical disc is as shown by the solid lines. The
laser beam L_1 is converged onto the information layer of

5   the thin cover type optical disc D1 through the thin cover
layer.

[0039]   When the thick cover type optical disc D2 is used,
the CD module 22 is driven to emit the laser beam L_2 shown
by a broken line, and a relative position of the objective

10   lens 10 with respect to the optical disc is closer to
follow the change of the distance to the information layer
as shown by broken lines in Fig. 2. The laser beam L_2 is
converged onto the information layer of the thick cover
type optical disc D2 through the thick cover layer.

15   [0040]   The laser beam reflected from the information
layer of the optical disc D1 is received by the photo-
detector provided in the DVD module 21. The laser beam
reflected from the information layer of the optical disc D2
is received by the photo-detector provided in the CD module

20   22. Then, based on the output of the photo-detector, a
focusing error signal and a tracking error signal are
generated. When the information is to be reproduced, a
reproducing signal of recorded information is also
generated based on the output of the photo-detector.

25   [0041]   Next, the configuration of the diffractive lens

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structure formed on the first surface 11 of the objective lens 10 will be described.

[0042]   The diffractive lens structure formed in the common area RC functions such that a predetermined order (a first order, in the embodiment) diffraction light component having a short wavelength (657 nm or 660 nm) forms an appropriate wavefront for the thin cover type optical disc D1, and the same order diffraction light component having a long wavelength (785 nm or 790 nm) forms an appropriate wavefront for the thick cover type optical disc D2.

[0043]   The diffractive lens structure in the common area RC is formed such that a change of spherical aberration due to a change of thickness of the cover layer is compensated by a change of the wavelength of the incident beams. Namely, the diffractive lens structure in the common area RC is configured such that the spherical aberration changes in the undercorrected direction as the wavelength increases.

[0044]   Specifically, the spherical aberration changes in the overcorrected direction as the thickness of the cover layer increases. On the other hand, due to the above-described configuration of the diffractive lens structure in the common area RC, the spherical aberration changes in the undercorrected direction as the wavelength of the incident laser beam increases. In addition, a longer wavelength laser beam is used for the thick cover type

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optical disc D2 and a shorter wavelength light beam is used

for the thin cover type optical disc D1, as described above.

Accordingly, the change of the spherical aberration due to

a change of the thickness of the cover layer can be

5   counterbalanced by the change of the spherical aberration

due to the wavelength dependence realized by the

diffractive lens structure.

[0045]   The diffractive lens structure formed on the high

NA exclusive area RE is configured to exhibit a smaller

10   wavelength dependence in a spherical aberration than that

of the common area RC, and is designed such that a

spherical aberration at the short wavelength (657 nm or 660

nm) is adequately corrected for the thin cover type optical

disc D1.

15   [0046]   With this configuration, when the thin cover type

optical disc D1 is used, the spherical aberration of the

light, whose wavelength is 657 nm or 660 nm and which is

passed through each of the areas RC and RE, is well-

compensated. Therefore, the high NA condition is achieved,

20   and accordingly, a relatively small beam spot, which is

suitable for the high recording density optical disc D1,

can be formed on the information layer of the optical disk

D1.

[0047]   When the thick cover type optical disc D2 is used,

25   the spherical aberration of the light whose wavelength is

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790 nm or 785 nm and which is passed through the common area RC is well compensated. On the contrary, the spherical aberration of the light, whose wavelength is 790 nm or 785 nm and which is passed through the high NA exclusive area

5 RE, is not adequately compensated. Therefore, the laser beam of 790 nm or 785 nm passed through the high NA exclusive area RE diffuses over areas around and apart from the beam spot formed by the portion of the beam passed through the common area RC. As a result, the low NA can be

10 achieved. Accordingly, a large beam spot, which is suitable for the thick cover type optical disc having low recording density, is formed on the information layer of the optical disc D2.

[0048] In either of the cases where the disc D1 is used

15 and where the disc D2 is used, the laser beam passed through the outside area Rout diffuses sufficiently in contrast to the beam spot formed by the laser beam passed through the inside area Rin because there is a gap in the spherical aberration between the light passed through the

20 outside area Rout and the light passed through the inside area Rin.

[0049] Hereinafter, two numerical embodiments according to the invention will be described in detail. The objective lenses indicated below are designed for a CD/DVD compatible

25 optical pick-up that can use the thin cover type optical

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2.18 mm) is a continuous surface without any steps and continuously connected to the base curve of the high NA exclusive area RE. The second surface 12 of the objective lens 10 is a continuous aspherical surface without a diffractive lens structure.

[0052]   The common area RC and the high NA exclusive area RE of the first surface 11, and the second surface 12 are rotationally-symmetrical aspherical surfaces. Generally, a rotationally-symmetrical aspherical surface is expressed by the following equation:

$$X(h) = \frac{ch^2}{1+\sqrt{1-(1+K)c^2h^2}} + A_4 h^4 + A_6 h^6 + A_8 h^8 + A_{10}h^{10} + A_{12}h^{12}$$

where, X(h) is a sag, that is, a distance of a point, whose height from the optical axis is h, on the rotationally-symmetrical aspherical surface with respect a tangential plane, which is tangential to the surface at a point where the optical axis intersects with the surface. Symbol c represents a curvature (1/r) of the vertex of the surface, K is a conic constant, and A_4, A_6, A_8, A_{10} and A_{12} are aspherical surface coefficients of fourth, sixth, eighth, tenth and twelfth orders, respectively.

[0053]   An additional optical path length $\Phi(h)$, which is added by the diffractive lens structure, is expressed by the following optical path difference function:

$$\Phi(h) = (P_2 h^2 + P_4 h^4 + P_6 h^6 + \ldots) \times m \times \lambda$$

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disc D1 (e.g., DVD) having a cover layer of 0.6 mm, and the thick cover type optical disc D2 (e.g., CD or CD-R) having a cover layer of 1.2 mm. The objective lens 10 has the diffractive lens structure on the first surface 11 and

5 converges the first order diffraction beam onto the information layer of the optical disc.

First Embodiment

[0050]   Fig. 3 schematically shows the objective lens 10,

10 according to the first embodiment, and the thin cover type optical disc D1. The effective diameter of the objective lens 10 is 4.04 mm. The inside area Rin of the objective lens 10 is divided into the common area (0 ≤ h < 1.69 mm) and the high NA exclusive area (1.69 ≤ h < 2.02 mm), where

15 h represents a height from the optical axis. The diffractive lens structures formed in the common area RC and in the high NA exclusive area RE are defined by different optical path difference functions, respectively.

[0051]   A base curve of the common area RC, which is the

20 shape of a lens surface of the refractive lens without the diffractive lens structure in the common area RC, is a rotationally-symmetrical aspherical surface that is different from a base curve of the high NA exclusive area RE, which is also a rotationally-symmetrical aspherical

25 surface. The surface of the outside area Rout (2.02 ≤ h <

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where P_2, P_4 and P_6 are coefficients of second, fourth and sixth orders, h represents a height from the optical axis, m represents a diffraction order, and λ represents a working wavelength. The optical path difference $\Phi(h)$

5 indicates a difference of an optical path length of a hypothetical ray of light which does not pass through the diffractive lens structure and an optical path length of a ray of light which is diffracted by the diffraction lens structure, at the height h from the optical axis. In other

10 words, the optical path difference $\Phi(h)$ represents the additional optical path length of each ray of light which is diffracted by the diffractive lens structure.

[0054] An actual microscopic shape of the diffractive lens structure is defined by subtracting $\lambda \times m$ (m :

15 integer), i.e., an integral multiple of λ, from $\Phi(h)$ to have a stepwise additional optical path length $\Phi'(h)$, similar to the Fresnel lens. Specifically, the additional optical path length $\Phi'(h)$ is expressed by the following formula.

20 $$\Phi'(h)=(MOD(P_2h^2+P_4h^4+P_6h^6+\ldots+CONST,\ 1)\ -CONST)\times\lambda_B$$

where, MOD is a modulo function, and λ_B is a blazed wavelength, at which an optical path length difference generated by the minute step of the diffractive lens structure becomes equal to one wavelength, i.e.,

25 diffraction efficiency is maximized. The constant CONST

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defines a phase of a boundary between the annular zones and could be an arbitrary value satisfying a condition: $0 \leq$ CONST < 1. It should be noted that the modulo function MOD (x, y) represents a remainder when x is divided by y.

5 When MOD $(P_2h^2+P_4h^4+P_6h^6+\ldots+\text{CONST}, 1)$ is equal to zero, a position at the height h, from the optical axis, represents the position of the boundary between two annular zones.

[0055] Data of the objective lens 10 according to the first embodiment is shown in TABLE 1 below.

TABLE 1

	NA$_1$=0.60 f$_1$=3.360 λ_1=657nm NA$_2$=0.50 f$_2$=3.384 λ_2=790nm			
	First surface			Second surface
	Common area (0≤h<1.69)	High-NA exclusive area (1.69≤h<2.02)	Outside area (2.02≤h<2.18)	
r	2.101	2.129	2.129	-8.450
κ	-0.500	-0.500	-0.500	0.0
A$_4$	-1.81100×10^{-3}	-6.72000×10^{-4}	-6.72000×10^{-4}	1.60200×10^{-2}
A$_6$	-2.44900×10^{-4}	-1.46200×10^{-5}	-1.46200×10^{-5}	-3.26800×10^{-3}
A$_8$	-1.75000×10^{-5}	-8.69200×10^{-5}	-8.69200×10^{-5}	1.29900×10^{-4}
A$_{10}$	-3.51400×10^{-6}	2.19000×10^{-5}	2.19000×10^{-5}	3.20300×10^{-5}
A$_{12}$	-2.56000×10^{-6}	-5.36100×10^{-6}	-5.36100×10^{-6}	-3.74500×10^{-6}
P$_2$	0.0	-2.56044	-	-
P$_4$	-1.65300	-0.80000	-	-
P$_6$	-0.15050	-0.09000	-	-
P$_8$	0.0	0.0	-	-
P$_{10}$	0.0	0.0	-	-
P$_{12}$	0.0	0.0	-	-
D	2.210			
n657	1.54059			

n790	1.53653

[0056]   TABLE 1 shows the coefficients that define the base curve and the diffractive lens structure of the common area RC, the coefficients that define the base curve and the diffractive lens structure of the high NA exclusive area RE, the coefficients that define the outside area, the coefficients that define the second surface 12, the distance D along the optical axis between the surfaces 11 and 12 of the objective lens 10, and refractive indices $n657$ and $n790$ at the wavelengths of 657 nm and 790 nm, respectively. In TABLE 1, NA_1, f_1 and λ_1 denote a numerical aperture, a focal length (unit: mm) and a wavelength (unit: nm) for the thin cover type optical disc D1, and NA_2, f_2 and λ_2 denote a numerical aperture, a focal length (unit: mm) and a wavelength for the thick cover type optical disc D2, respectively. Further, r denotes a radius of curvature of a surface at a paraxial portion of the surface.

[0057]   Figs. 4A-4C show aberrations of the optical system including the objective lens 10 according to the first embodiment and the cover layer of the optical disc. Fig. 4A shows a spherical aberration SA and sine condition SC in a case where the thin cover type optical disc is used and the radius of the light beam incident on the objective lens 10 is 2.18 mm.

[0058]   Fig. 4B shows a spherical aberration SA and sine

condition SC in a case where the thin cover type optical disc is used and the radius of the light beam incident on the objective lens 10 is 2.02 mm.

[0059]   Fig. 4C shows a spherical aberration SA and sine condition SC in relation to NA (for NA<0.50) when the thick cover type optical disc is used.

[0060]   As shown in Fig. 4A, the spherical aberration has a gap of approximately 200 micrometers between the inside area Rin and the outside area Rout. It should be noted that, if the absolute value of the gap between the spherical aberrations caused by the inside area Rin and outside area Rout is 10 micrometers or greater, the light beam passed through the outside area Rout is effectively diffused. In the embodiment, the gap is much greater than 10 micrometers, the light beam passed through the outside area Rout is sufficiently diffused in contrast to the beam spot formed by the light beam passed through the inside area Rin.

[0061]   Fig. 5 shows a spot diagram on the information layer when the thin cover type optical disc is used. It should be noted that the light beam passed through the inside area Rin converges onto a point P1, while the light beam passed through the outside area Rout is diffused over an annular area which is spaced from the point P1 by approximately 100 micrometers. Therefore, the light beam passed through the outside area Rout does not affect the

beam spot formed by the light beam passed through the inside area Rin even though no aperture stop member or the like is provided.

5   SECOND EMBODIMENT

[0062]   Data of the objective lens 10 of a second embodiment is shown in TABLE 2 below.

TABLE 2

	NA₁=0.60 f₁=2.340 λ₁=660nm NA₂=0.53 f₂=2.360 λ₂=785nm			
	First surface			Second surface
	Common area $(0 \leq h < 1.25)$	High-NA exclusive area $(1.25 \leq h < 1.40)$	Outside area $(1.40 \leq h < 1.50)$	
R	1.580	1.533	1.533	-5.288
κ	-0.520	-0.520	-0.520	0.0
A4	-8.30300×10^{-3}	-4.30300×10^{-3}	-4.30300×10^{-3}	4.26300×10^{-2}
A6	-9.77300×10^{-4}	-1.39500×10^{-3}	-1.39500×10^{-3}	-9.63400×10^{-3}
A8	3.59400×10^{-4}	1.71700×10^{-3}	1.71700×10^{-3}	-3.48400×10^{-3}
A10	-6.68900×10^{-4}	-1.23600×10^{-3}	-1.236000×10^{-3}	3.49900×10^{-3}
A12	-1.34300×10^{-4}	2.54100×10^{-4}	2.54100×10^{-4}	-7.10600×10^{-4}
P₂	0.0	-4.42763	-	-
P₄	-7.57700	-4.87000	-	-
P₆	-0.73830	-0.60200	-	-
P₈	-0.13650	0.0	-	-
P₁₀	0.0	0.0	-	-
P₁₂	0.0	0.0	-	-
D	1.400			
n660	1.54044			
n785	1.53665			

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[0063]   The effective diameter of the objective lens 10

is 2.80 mm. Similarly to the first embodiment, the inside
area Rin of the objective lens 10 is divided into the
common area RC (0 ≤ h < 1.25 mm) and the high NA exclusive
area RE (1.25 ≤ h < 1.40 mm), where h represents a height

5   from the optical axis. The diffractive lens structure
formed in the common area RC is defined by an optical path
difference function which is different from that defining
the high NA exclusive area RE.

[0064]   A base curve of the common area RC, which is a

10   shape of the surface of a refractive lens excluding the
diffractive lens structure, is a rotationally-symmetrical
aspherical surface that is different from the base curve of
the high NA exclusive area RE, which is also a
rotationally-asymmetrical aspherical surface. The surface

15   of the outside area Rout (1.40 ≤ h < 1.50 mm) is a
continuous surface with no diffraction lens structure and
continuously connected with the base curve of the high NA
exclusive area RE. The second surface is a continuous
aspherical surface without diffraction lens structure.

20   [0065]   Figs. 6A-6C show aberrations of the optical
system including the objective lens and the cover layer of
the optical disc. Fig. 6A shows a spherical aberration SA
and sine condition SC in a case where the thin cover type
optical disc is used and the radius of the light beam

25   incident on the objective lens 10 is 1.50 mm.

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[0066]   Fig. 6B shows a spherical aberration SA and sine condition SC in a case where the thin cover type optical disc is used and the radius of the light beam incident on the objective lens 10 is 1.40 mm.

[0067]   Fig 6C shows a spherical aberration SA and sine condition SC in relation to NA (for NA<0.53) when the thick cover type optical disc is used.

[0068]   As shown in Fig. 6A, the spherical aberration has a gap of approximately 200 micrometers between the inside area Rin and the outside area Rout. Therefore, the light beam passed through the outside area Rout is sufficiently diffused in contrast to the beam spot formed by the light beam passed through the inside area Rin.

[0069]   Fig. 7 shows a spot diagram on the information layer when the thin cover type optical disc is used. It should be noted that the light beam passed through the inside area Rin converges onto a point P2, while the light beam passed through the outside area Rout is diffused over an annular area which is spaced from the point P2 by approximately 100 micrometers. Therefore, the light beam passed through the outside area Rout does not affect the beam spot formed by the light beam passed through the inside area Rin.

[0070]   As described above, a gap of the spherical aberration (shown in Fig.4A and Fig. 6A) is caused between

the inside area Rin and the outside area Rout so as to prevent the light beam passed through the outside area Rout from affecting the beam spot formed by the light beam passed through the inside area Rin. According to the above-described embodiments, the gap of the spherical aberrations is caused by forming the outside area as a surface which does not have a diffraction lens structure, and is continuously connected to the base curve of the high NA exclusive area RE.

[0071]   Alternatively, the affect of the light beam incident on the outside area Rout of the lens can also be prevented by forming the outside area Rout as a reflective surface, a light absorptive surface or a light scattering surface. If the outside area Rout is formed to be the light scattering surface, however, it becomes necessary to scratch the outside area in a random fashion to form the scattering surface after the molding process. Further, if the outside area Rout is formed to be the reflective surface or the light absorptive surface, it becomes necessary to coat the outside area Rout. In view of such an extra process required, the configuration according to the embodiments is advantageous in comparison with the alternative configurations above.

[0072]   The present disclosure relates to the subject matter contained in Japanese Patent Application No. 2000-

236717, filed on August 4, 2000, which is expressly incorporated herein by reference in its entirety.